Original Article

A comparative study of L4-L5-S1 and L5-S1 vertebral fusion in high-grade L5-S1 spondylolisthesis

ABSTRACT

Introduction: One of the most common types of spinal diseases is spondylolisthesis, which in advanced cases requires surgical intervention. This study aimed to compare the results of L4-L5-S1 and L5-S1 vertebral fusion treatment in high-grade L5-S1 spondylolisthesis.

Methods: A study design that randomized controlled trial. A total of 70 consecutive patients who underwent surgery for the treatment of spondylolisthesis at Al-Zahra Hospital in Isfahan, Iran, were evaluated from July 2020 to February 2021 (35 patients underwent L4-L5-S1 and 35 received L5-S1 vertebral fusion treatment). The radicular and low back pain (LBP) intensity (Vanguard Australian Shares), blood loss, wound infection, reduction, and quality of life (SF-12 scores) were quantified before the surgery, 1, 3, and 6 months after surgery in two groups.

Results: Patients involved in the two groups had similar baseline demographic characteristics. The percent slip in L4-L5-S1 and L5-S1 group, respectively, postoperative 81.11% and 57.89%, $P = 0.0001$. Intraoperative blood loss and postoperative were higher in the L4-L5-S1 group when compared to the L5-S1 group ($P < 0.05$). The wound infection rate of the L4-L5-S1 group was similar to that of the L5-S1 group (8.6% vs. 2.9%, $P = 0.303$). There was no difference in radicular and LBP intensity, SF-12 scores among patients with L4-L5-S1 and L5-S1 groups ($P < 0.05$).

Conclusion: Both L4-L5-S1 and L5-S1 were equally beneficial in improving short-term functional outcomes for patients with high grade L5-S1 spondylolisthesis. However, L4-L5-S1 was associated with statistically significant higher incidences of blood loss, but it was accompanied by a better reduction. Therefore, caution should be exercised when considering L4-L5-S1.

Keywords: Back pain, high-grade L5-S1 spondylolisthesis, radicular pain, reduction, surgical technique, vertebral fusion

INTRODUCTION

Low back pain (LBP) is one of the most common musculoskeletal disorders in different communities.[1] The prevalence of LBP is estimated to be between 30 and 80% among the general population and has been found to increase with age;[2] approximately 85% of these people are in the category of nonspecific LBP and 15% of them have a specific pathoanatomical origin for LBP and are in the group of patients with specific LBP.[3-5]

One of the pathobiomechanical and pathoanatomical causes of LBP is spondylolisthesis, which directly affects the vertebrae and is most often seen in the lumbar spine.[6] Spondylolysis is an anatomical defect or fracture of the pars interarticularis of the vertebral arch. It occurs at the L5 vertebrae between 85% and 95% of the time and occurs at the L4 vertebrae 5%–15% of the time.[7]

Access this article online	
Website: www.jcvjs.com	Quick Response Code
DOI: 10.4103/jcvjs.jcvjs_41_21	

Majid Rezvani, Masih Sabouri[1], Mehdi Mahmoodkhani[2], Ali Mokhtari[3], Donya Sheibani Tehrani[4]

Department of Neurosurgery, School of Medicine, Neurosciences Research Center, Al-Zahra Hospital, Isfahan University of Medical Sciences, [1]Department of Neurosurgery, School of Medicine, Medical Image and Signal Processing Research Center, Al-Zahra Hospital, Isfahan University of Medical Sciences, [2]Department of Neurosurgery, School of Medicine, Neurosciences Research Center, Kashani Hospital, Isfahan University of Medical Sciences, [3]Department of Neurosurgery, Isfahan University of Medical Sciences, Isfahan, [4]Department of IT, Shahid Beheshti University, Tehran, Iran

Address for correspondence: Dr. Ali Mokhtari, Department of Neurosurgery, Isfahan University of Medical Sciences, Isfahan, Iran.
E-mail: alimokhtary2001@yahoo.com

Submitted: 26-Mar-21 **Accepted:** 05-Apr-21
Published: 10-Jun-21

How to cite this article: Rezvani M, Sabouri M, Mahmoodkhani M, Mokhtari A, Tehrani DS. A comparative study of L4-L5-S1 and L5-S1 vertebral fusion in high-grade L5-S1 spondylolisthesis. J Craniovert Jun Spine 2021;12:202-8.

Spondylolysis has been shown to be absent at birth, and generally develops at a young age.[8] Lemoine *et al*.[9] performed a prospective study on 532 patients under 8 years a prevalence of spondylolysis was 1% in children under age 3, 3.7% in children under age 6 and 4.7%. Ko and Lee[10] found that prevalence of LBP was 36.37% and the prevalence of lumbar spondylolysis in a selected population, who visited hospital for abdominal or urological lesions except LBP, was 9.12% based on computed tomography (CT) imaging. Males demonstrated a similar presence of LBP to females but a significantly higher incidence of spondylolysis. The prevalence of spondylolysis was not associated with the presence of LBP and age in adulthood.

Spondylolisthesis refers to degenerative changes in the spine that are characterized by lumbosacral deformity, dislocated vertebrae, fractures, or other deformities of the pars interaticularis[6] and is generally the anterior displacement of one vertebra over another vertebra. In all cases, there is a defect in the posterior part of the vertebra. Spondylolisthesis may be completely asymptomatic. Chronic, mild back pain is the most common complaint that may be accompanied by intermittent radicular pain or lameness. In case of mild chronic back pain, supportive treatments, including rest, prescribing painkillers, and wearing a medical belt are recommended, but in severe and progressive cases or intermittent neurological symptoms and lameness, surgery is recommended.[11]

Different imaging methods such as plain radiography, CT scan, and MRI can be used to diagnose spondylolisthesis.[12] The traditional method of surgical treatment of high-grade spondylolisthesis is the Gill method, which slips by removing the posterior and loose parts of the vertebrae and is a posterolateral fusion without instrumentation,[13] but it was later determined if this method uses pedicular screws, the vertebral fusion will be more resistant.[14]

The Cotrel-Dubousset system was developed in the 1980s, and the benefits of using pedicular screws have been reported by Cotrel, Roy Camille, and Steffee since the mid-1980s.[15] Although many studies have been conducted on the advantages and disadvantages of vertebral fusion with instrumentation compared to the traditional method (without instrumentation), the physical and biomechanical properties of the spine in improving spondylolisthesis have received less attention and such expression. It has been found that in vertebral fusion using pedicular screws, fewer segments of the spine are involved and in terms of stability, it creates more strength in rotation and translation positions.[16,17]

The use of this method causes the patient to return to normal and daily activities faster and also reduces the length of hospital stay and immobility.[16] However, this type of technique is safer, more effective, and has a better fusion rate.[18] Furthermore, the biomechanical properties of fusion with pedicle screws (PSs) are excellent, but this technique is associated with significant surgical risk[19] and necessary measures must be taken to minimize postoperative complications.

Surgical management of high-grade spondylolisthesis involves various techniques such as instrumentations, reductions, and decompressions. Instrumentation plays a more significant role in adults than children as uninstrumented *in situ* circumferential fusion is considered more viable in treating pediatric high-grade spondylolisthesis.[20]

A method of lumbosacral fixation that has been used successfully in moderate grades of spondylolisthesis at our institution involves the use of transdiscal S1 PSs. With this technique, S1 PSs are placed through the S1 pedicle, through the superior endplate of S1, through the inferior endplate of L5, to terminate in the L5 body. Transpedicular screw L4-L5-S1 fixation is an established, common procedure performed by spine surgeons that requires correct placement of PSs to provide biomechanical stability and to avoid injuries in neighboring neurovascular structures.[21]

Postoperative care is one of the most important measures in the success of the treatment of spondylolisthesis, and in addition to educating the patient and companions about adhering to the standards of care, taking measures that help make the spine more stable and the spine return faster is very important. Therefore, in this study, the effect of fusion of L4-L5-S1 vertebrae compared to L5-S1 vertebral fusion on healing and reduction of pain and other symptoms of high-grade L5-S1 spondylolisthesis will be investigated.

METHODS

The present study was performed as a randomized clinical trial study and as a 6-month follow-up period from July 2020 to February 2021 in Al-Zahra Hospital in Isfahan, Iran. (IRCT Registration Reference: IRCT20201130049541N1). The target population included patients with high-grade L5-S1 spondylolisthesis who were admitted to the center for spinal fixation with fusion surgery.

Inclusion criteria included patients with high-grade spondylolisthesis L5-S1 (The spondylolistheses are divided into high (slippage >50%) and low (slippage <50%) grade).[22]

Candidate for vertebral fusion with instrumentation, slip on the surface of a vertebra, age <80 years and patients consented to participate in the study. Exclusion criteria included patients who suffer from complications of surgery (root injury, rupture of the sac, etc.), patients with neurological defects who need emergency surgery, patients with a history of underlying diabetes, who have neuropathy, patients with a history of severe heart disease and preoperative anticoagulant use, as well as patients who are smokers or addicted to alcohol and drugs, and bone metabolic diseases.

According to the entry and exit criteria and the study of Zhang *et al*.,[23] in 2017 and based on the formula of the following sample volume at a significant level of 0.05, the test power is 80% and considering 5% of the sample drop, 70 samples of this study were selected.

$$n = \frac{(Z_{1-\frac{\alpha}{2}} + Z_{1-\beta})^2 \times (S_1^2 + S_2^2)^2}{(mean_1 - mean_2)^2} = \frac{(1.96 + 0.84)^2 (1.2^2 + 0.8^2)^2}{(5 - 4.3)^2}$$

$$= \frac{31.86}{0.49} = 69.12 \cong 70$$

The research samples were divided into two groups of 35 people using random number generation software and the random allocation method. The work of vertebral fixation in the first group (L4-L5-S1) was performed on the surface of L4-L5-S1 vertebrae using PSs and the instrumentation method by which three lumbar vertebrae were fixed [Figure 1].

In the second group (L5-S1), the device was placed on the surface of the L5-S1 vertebrae using pedicular screws and two lumbar vertebrae were fixed. L5-S1 interbody fusion was performed for all groups of patients using allograft bone [Figure 2].

At the beginning of the patients' study, the demographic information of the disease, including age, sex, height and weight, and information about the disease, including slippery vertebrae, cause of vertebral slip, body mass index, and duration of the disease were recorded in the data collection form. Preoperatively, the severity of LBP and radicular pain in patients was assessed using the Vanguard Australian Shares (VAS) Index (score zero: painless to score 10: most severe pain) [Table 1].

Reduction was assessed according to The Meyerding classification [Figure 3].[24]

The Myerding classification defines the amount of vertebral slippage on X-ray in reference to the caudal vertebrae.

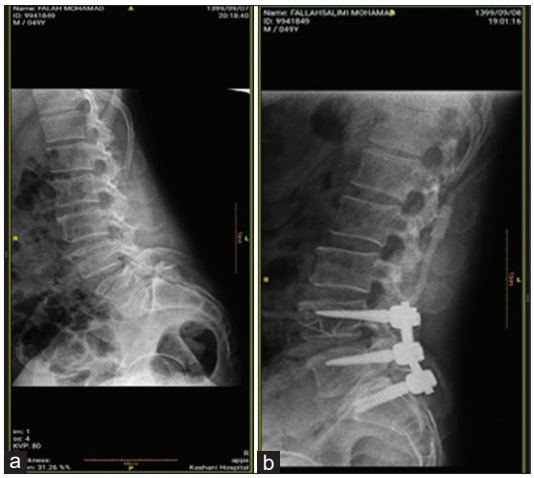

Figure 1: (a): Before, (b): After, L4-L5-S1 group

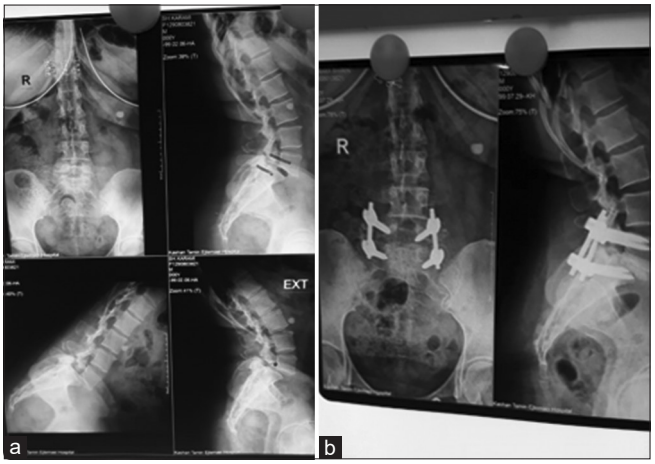

Figure 2: (a): Before, (b): After, L5-S1 Group

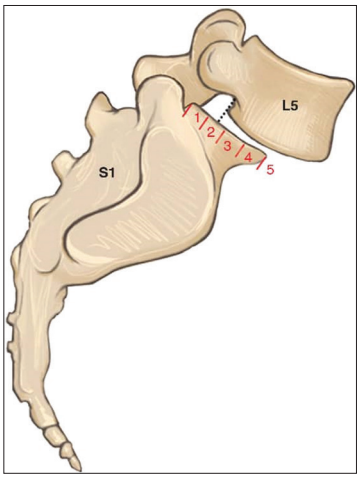

Figure 3: The Meyerding classification

There are five grades of spondylolisthesis in the Myerding classification. Grade I is <25% slippage, Grade II is 26%–50% slippage, Grade III is 51%–75% slippage, grade IV is 76%–100% slippage, and Grade V is over 100% slippage and is referred to as spondyloptosis.

Other symptoms of the disease were determined in the examination of patients and the result was recorded in the data collection form. After surgery and completion of the hospitalization period and after providing care training to the patient and his companions, patients were asked to come at the specified time intervals (1 month, 3 months, and 6 months after the surgery) for re-evaluation and additional examinations. After referral at the mentioned time intervals, the severity of LBP and radicular pain and complications of the operation such as infection and bleeding and the percentage of reduction were assessed by X-ray. Finally, patients' Quality of life was determined by a Health Survey Short Form (SF-12) from questionnaire the patients before and 6 months after the operation.

The SF-12 is a self-administered questionnaire, which measures health status. Responses to questions are dichotomous (yes/no), ordinal (excellent to poor), or expressed by a frequency (always to never). The answers to this 12-item questionnaire allow calculation of Physical Component Summary and a Mental Component Summary scores. In the absence of response to a single question of these subscales, the score cannot be calculated. The higher the score, the better the health status.[25]

To determine the frequency tables, number and percentage indices were used for qualitative variables, and for quantitative variables mean and standard deviation were used. Due to the normal distribution of quantitative variables, repeated measure ANOVA, paired sample *t*-test, and independent samples *t*-test and to determine the relationship between qualitative variables, the Pearson Chi-squared test and Fisher's exact test were used. Statistical analyses were performed using SPSS software version 21. In this study, a statistically significant level of 0.05 was considered.

RESULTS

In this clinical trial study, 70 patients were randomly assigned to the two groups of vertebral fusion treatment L4-L5-S1 and L5-S1. Twelve men (34.3%) and 23 women (65.7%) were in the L4-L5-S1 group and 13 men (37.1%) and 22 women (62.9%) were in the L5-S1 group. The mean age in the L4-L5-S1 group is 61.28 with a standard deviation of 7.94 years and in the L5-S1 group is 58 with a standard deviation of 7.13 years. Furthermore, the body mass index in L4-L5-S1 group is 24.92 with a standard deviation of 5.09, and in L5-S1 group is 25.40 with a standard deviation of 5.41. In this study, BMI, gender, age, heights, and weight were homogeneous in both groups [Table 2].

Table 1: Vanguard Australian shares index

Quality of pain	Score
No pain	1
Mild pain	2
Pain that cause the patient discomfort	3
Pain that cause the patient searching medical care	4
Moderate pain that is still supportable	5
Pain that make the patient fill completely discomfort	6
Pain that cause the patient to stop all activities	7
Severe pain rarely have been experienced	8
Very severe pain	9
Pain as worst as possible pain	10

Table 2: Investigating the homogeneity of the two groups

		Mean±SD	*P**
Age			
L4-L5-S1		61.28±7.94	0.073
L5-S1		58±7.13	
Height			
L4-L5-S1		170.74±8.64	0.068
L5-S1		165.85±12.93	
Weight			
L4-L5-S1		71.85±11.37	0.278
L5-S1		68.94±10.91	
BMI			
L4-L5-S1		24.92±5.09	0.704
L5-S1		25.40±5.41	
	Sex	***n* (%)**	***P****
L4-L5-S1	Male	12 (34.3)	0.803
	Female	23 (65.3)	
L5-S1	Male	13 (37.1)	
	Female	22 (62.9)	

*Independent sample *t*-test, **Pearson Chi-square test. SD - Standard deviation

According to independent *t*-test regarding the Intensity of radicular pain before the intervention, there was no significant difference between the two groups ($P = 0.342$). As well as 1 month ($P = 0.195$), 3 months ($P = 0.593$), and 6 months after the intervention ($P = 1.000$), the Intensity of Radicular Pain was not significantly in two groups. Repeated measures ANOVA showed that the mean Intensity of Radicular Pain differed significantly between different times in two groups ($P = 0.0001$) [Table 3].

The results showed according to independent *t*-test regarding the severe back pain before the intervention, there was no significant difference between the two groups ($P = 0.506$). As well as 1 month ($P = 0.865$), 3 months ($P = 0.860$), and 6 months after the intervention ($P = 0.337$), the Severe Back Pain was not significantly in two groups. Repeated measures ANOVA showed that the mean Severe Back Pain differed significantly between different times in two groups ($P = 0.0001$) [Table 3].

Furthermore, bleeding during and after surgery in L5-S1 group was significantly less than L4-L5-S1 group ($P < 0.05$).

Table 3: Summary of the results of the analysis of the variables of low back pain intensity and radicular pain intensity

	Mean±SD		Independent *t*-test	
	L4-L5-S1	L5-S1	*t*	*P*
Intensity of radicular pain				
Before	5.62±1.94	5.17±2.05	0.958	0.342
1 month later	4.80±1.76	4.26±1.70	0.671	0.195
3 months later	3.29±1.82	3.06±1.73	0.491	0.593
6 months later	1.66±1.68	1.66±1.57	0.725	1.000
ANOVA (*F*, *P*)	0.917, 0.0001	0.289, 0.0001		
Severe back pain				
Before	5.64±2.29	5.11±2.36	−0.669	0.506
1 month later	4.63±2.07	4.54±2.12	0.880	0.865
3 months later	3.63±2.13	3.54±1.92	0.402	0.860
6 months later	2.51±2.27	2.03±1.92	0.132	0.337
ANOVA (*F*, *P*)	0.447, 0.0001	0.029, 0.0001		

SD - Standard deviation

Table 4: Summary of postoperative complication analysis results

	Mean±SD		Independent *t*-test	
	L4-L5-S1	L5-S1	*t*	*P*
Bleeding rate				
During the operation (ml)	636.57±159.15	295.71±75.82	16.71	0.0001
After surgery (ml)	377±141.98	210.57±64.03	11.43	0.0001
Paired sample *t*-test (*t*, *P*)	−18.33, 0.0001	−17.70, 0.0001		
Reduction				
After surgery (%)	81.11 (5.94)	57.89 (5.68)	0.795	0.0001
Infection, *n* (%)				
Yes	3 (8.6)	1 (2.9)	0.303*	
No	32 (91.4)	34 (97.1)	0.614**	

*Pearson Chi-square test, **Fisher's exact test. SD - Standard deviation

Table 5: Numeric scores of the SF-12 in patients with L4-L5-S1 and L5-S1 treatment group

Test score	L4-L5-S1		L5-S1		*P**
	Mean±SD	Range	Mean±SD	Range	
Before					
MCS	24.31±10.45	15-32	25.09±10.07	16-34	0.340**
PCS	27.31±9.12	15-34	26.87±9.32	15-35	0.137***
6 months later					
MCS	42.95±11.85	16-60	43.11±12.05	13-62	0.610**
PCS	45.64±9.13	21-67	44.98±9.35	20-68	0.640***
P	0.0001		0.0001		

*Significance of total scores ($P<0.05$), **Mann-Whitney test, ***Student's *t*-test. SD - Standard deviation, MCS - Mental component summary, PCS - Physical component summary

Meanwhile, the percentage of reduction in L4-L5-S1 treatment group is significantly higher than the percentage of reduction in L5-S1 treatment group ($P < 0.05$) [Table 4].

Of patients, 8.6% in the L4-L5-S1 treatment group and 2.9% in the L5-S1 treatment group became infected. The results of statistical tests showed that the type of group therapy and the prevalence of infection in patients were not significantly related ($P > 0.05$) [Table 4].

Results of numeric mental and physical scores of the SF-12 in patients with two groups are presented in Table 5. There were no significant differences in both mental and physical numeric scores ($P > 0.05$, for both scores) between patients with L4-L5-S1 and L5-S1 treatment group. However, there were a significant differences in both mental and physical numeric scores ($P < 0.05$, for both scores) between score before and after 6 months in two groups.

DISCUSSION

Spondylolisthesis refers to degenerative changes in the spine that are often treated with supportive therapies

and in severe cases requires surgical intervention[26] and remains a challenge for orthopedic surgeons, neurosurgeons and pediatrics[27] The optimal treatment of high-grade spondylolisthesis is a controversial issue. It is well known that symptomatic high-grade slip, resistant to conservative management requires surgical stabilization.[28]

The classification system proposed by Spinal Deformity Study Group is practical and easy to apply and should be used and more studied in our country. The purpose of this classification emphasizes that patients with spondylolisthesis L5/S1 form a heterogeneous group with several postural adjustments and that this should be considered by physicians when indicating any type of treatment.[29]

Minamide *et al*., 18 fresh human cadaveric (age 59–88 years) L5-S1 motion segments were obtained. There were no differences in stiffness between transdiscal fixation and combined interbody/PS fixation. Spondylolisthesis was then simulated by displacing L5 on S1 (% slip average = 41.3%) were more likely to present research (57.89%) findings.[30]

Thomas *et al*., the rate of failure of indirect decompression in lateral single-position surgery from L4 to S1 is exceedingly low. This low risk of failure should be weighed against the risks associated with direct decompression as well as the risks of the extra operative time needed to perform this decompression.[31]

In the study of Wang *et al*.,[32] the fixation of two vertebral surface with the fixation of three vertebral surfaces in fusion operation by the spinal device in groups of patients with spondylolisthesis grades 1 and 2 was examined and compared. Recovery time in the two-level stabilization group was significantly longer than one-level fixation. In our study, the recovery time was the same in both methods.

In the study of Ames *et al*.,[33] the effect of vertebral device level in improving the symptoms of spondylolisthesis was studied. Implantation of pedicular screws did not have a significant effect on the amount and duration of recovery.

In his study, Farzanegan[34] evaluated 48 patients with spondylolisthesis who underwent fixation surgery with CD-type pedicular screws over a period of 3 years for the improvement of symptoms as well as postoperative complications and stated that lumbar fusion in the above method resulted in proper performance, patient satisfaction and a low percentage of complications, which is consistent with the results of our study.

The goals for surgical correction of high-grade spondylolisthesis are to arrest the progression of listhesis, achieve decompression of neural elements, and prevent a worsening slip angle. Any reductive technique of high-grade spondylolisthesis is controversial.

All reported that although fusion and reduction achieve a higher rate of fusion, this does not necessarily lead to better clinical or functional outcomes.

To the best of our knowledge, no other studies have been published reporting the use of L4-L5-S1 and L5-S1 vertebral fusion in adolescents with high-grade L5-S1 spondylolisthesis and the patient in our report demonstrated Decrease low-back pain and radicular pain in two groups.

This study has several limitations. A possible reason was that follow-up periods were not long enough to confirm the results. Further multicenter studies with more patients and longer follow-up should be performed.

CONCLUSION

According to the results of this study, the intensity index of radicular pain and the severity of LBP and infection rate were almost the same in L4-L5-S1 and L5-S1 vertebral fusion at each time, and there was no significant advantage in either group. Bleeding during and after surgery in L5-S1 group was significantly less than L4-L5-S1 group. Furthermore, the percentage of reduction in L4-L5-S1 treatment group is significantly higher than the reduction rate in L5-S1 treatment group. Finally, there were no significant differences in both mental and physical numeric scores between patients with two groups.

Acknowledgments

We acknowledge all those who contributed toward conducting this study.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Jin K, Sorock GS, Courtney TK. Prevalence of low back pain in three occupational groups in Shanghai, People's Republic of China. J Safety Res 2004;35:23-8.
2. Morris LD, Daniels KJ, Ganguli B, Louw QA. An update on the prevalence of low back pain in Africa: A systematic review and meta-analyses. BMC Musculoskelet Disord 2018;19:196.

3. Süüden E, Ereline J, Gapeyeva H, Pääsuke M. Low back muscle fatigue during Sørensen endurance test in patients with chronic low back pain: Relationship between electromyographic spectral compression and anthropometric characteristics. Electromyogr Clin Neurophysiol 2008;48:185-92.
4. Davarian S, Maroufi N, Ebrahimi I, Farahmand F, Parnianpour M. Trunk muscles strength and endurance in chronic low back pain patients with and without clinical instability. J Back Musculoskelet Rehabil 2012;25:123-9.
5. O'Sullivan P. It's time for change with the management of non-specific chronic low back pain. Br J Sports Med 2012;46:224-7.
6. Dritsa D, Bettany-Saltikov J, Hanchard N, editors. Exercise versus surgical intervention for pain and disability in adults with lumbar spondylolisthesis. In: 13th International Conference on Conservative Management of Spinal Deformities and First Joint Meeting of the International Research Society on Spinal Deformities and the Society on Scoliosis Orthopaedic and Rehabilitation Treatment 2016. Banff, Canada; 2017.
7. Gagnet P, Kern K, Andrews K, Elgafy H, Ebraheim N. Spondylolysis and spondylolisthesis: A review of the literature. J Orthop 2018;15:404-7.
8. Mataliotakis G, Tsirikos A. Spondylolysis and spondylolisthesis in children and adolescents: Current concepts and treatment. Spine 2017;31:P395-401.
9. Lemoine T, Fournier J, Odent T, Sembély-Taveau C, Merenda P, Sirinelli D, *et al*. The prevalence of lumbar spondylolysis in young children: A retrospective analysis using CT. Eur Spine J 2018;27:1067-72.
10. Ko SB, Lee SW. Prevalence of spondylolysis and its relationship with low back pain in selected population. Clin Orthop Surg 2011;3:34-8.
11. Boswell MV, Trescot AM, Datta S, Schultz DM, Hansen HC, Abdi S, *et al*. Interventional techniques: Evidence-based practice guidelines in the management of chronic spinal pain. Pain Physician 2007;10:7-111.
12. Luo X, Pietrobon R, Sun SX, Liu GG, Hey L. Estimates and patterns of direct health care expenditures among individuals with back pain in the United States. Spine (Phila Pa 1976) 2004;29:79-86.
13. Attal N, Perrot S, Fermanian J, Bouhassira D. The neuropathic components of chronic low back pain: A prospective multicenter study using the DN4 Questionnaire. J Pain 2011;12:1080-7.
14. Du Bois M, Szpalski M, Donceel P. Patients at risk for long-term sick leave because of low back pain. Spine J 2009;9:350-9.
15. Yamashita K, Tezuka F, Manabe H, Morimoto M, Hayashi F, Takata Y, *et al*. Successful endoscopic surgery for L5 radiculopathy caused by far-lateral disc herniation at L5-S1 and L5 isthmic grade 2 spondylolisthesis in a professional baseball player. Int J Spine Surg 2018;12:624-8.
16. Du Plessis PN, Lau BP, Hey HW. Traumatic dislocation of the S1 polyaxial pedicle screw head: A case report. J Spine Surg 2017;3:95-101.
17. Kuklo TR, Bridwell KH, Lewis SJ, Baldus C, Blanke K, Iffrig TM, *et al*. Minimum 2-year analysis of sacropelvic fixation and L5-S1 fusion using S1 and iliac screws. Spine (Phila Pa 1976) 2001;26:1976-83.
18. Gibson JL, Vuong SM, Bohinski RJ. Management of autonomic dysreflexia associated with Charcot spinal arthropathy in a patient with complete spinal cord injury: Case report and review of the literature. Surg Neurol Int 2018;9:113.
19. Nevzati E, Marbacher S, Soleman J, Nicolas Perrig W, Diepers M, Khamis A, *et al*. Accuracy of pedicle screw placement in the thoracic and lumbosacral spine using a conventional intraoperative fluoroscopy-guided technique: A national neurosurgical education and training center analysis of 1236 consecutive screws. World Neurosurg 2014;82:866-71.e1-2.
20. Passias PG, Poorman CE, Yang S, Boniello AJ, Jalai CM, Worley N, *et al*. Surgical treatment strategies for high-grade spondylolisthesis: A systematic review. Int J Spine Surg 2015;9:50.
21. Jaeger A, Giber D, Bastard C, Thiebaut B, Roubineau F, Flouzat Lachaniette CH, *et al*. Risk factors of instrumentation failure and pseudarthrosis after stand-alone L5-S1 anterior lumbar interbody fusion: A retrospective cohort study. J Neurosurg Spine 2019;31:338-46.
22. Peng P, Chen K, Chen H, Zhang K, Sun J, Yang P, *et al*. Comparison of O-arm navigation and microscope-assisted minimally invasive transforaminal lumbar interbody fusion and conventional transforaminal lumbar interbody fusion for the treatment of lumbar isthmic spondylolisthesis. J Orthop Translat 2020;20:107-12.
23. Zhang D, Mao K, Qiang X. Comparing minimally invasive transforaminal lumbar interbody fusion and posterior lumbar interbody fusion for spondylolisthesis: A STROBE-compliant observational study. Medicine (Baltimore) 2017;96:e8011.
24. Petersen T, Laslett M, Juhl C. Clinical classification in low back pain: Best-evidence diagnostic rules based on systematic reviews. BMC Musculoskelet Disord 2017;18:188.
25. Lee MK, Oh J. Health-related quality of life in older adults: Its association with health literacy, self-efficacy, social support, and health-promoting behavior. Healthcare (Basel) 2020;8:407.
26. Parker SL, Mendenhall SK, Shau DN, Zuckerman SL, Godil SS, Cheng JS, *et al*. Minimally invasive versus open transforaminal lumbar interbody fusion for degenerative spondylolisthesis: Comparative effectiveness and cost-utility analysis. World Neurosurg 2014;82:230-8.
27. Kisa P, Grabski DF, Ozgediz D, Ajiko M, Aspide R, Baird R, *et al*. Unifying children's surgery and anesthesia stakeholders across institutions and clinical disciplines: Challenges and solutions from Uganda. World J Surg 2019;43:1435-49.
28. Palejwala A, Fridley J, Jea A. Transsacral transdiscal L5-S1 screws for the management of high-grade spondylolisthesis in an adolescent. J Neurosurg Pediatr 2016;17:645-50.
29. Tebet MA. Current concepts on the sagittal balance and classification of spondylolysis and spondylolisthesis. Rev Bras Ortop 2014;49:3-12.
30. Minamide A, Akamaru T, Yoon ST, Tamaki T, Rhee JM, Hutton WC. Transdiscal L5-S1 screws for the fixation of isthmic spondylolisthesis: A biomechanical evaluation. J Spinal Disord Tech 2003;16:144-9.
31. Thomas JA, Thomason CI, Braly BA, Menezes CM. Rate of failure of indirect decompression in lateral single-position surgery: Clinical results. Neurosurg Focus 2020;49:E5.
32. Wang J, Zhou Y, Zhang ZF, Li CQ, Zheng WJ, Liu J. Comparison of one-level minimally invasive and open transforaminal lumbar interbody fusion in degenerative and isthmic spondylolisthesis grades 1 and 2. Eur Spine J 2010;19:1780-4.
33. Ames CP, Acosta FL Jr., Chi J, Iyengar J, Muiru W, Acaroglu E, *et al*. Biomechanical comparison of posterior lumbar interbody fusion and transforaminal lumbar interbody fusion performed at 1 and 2 levels. Spine (Phila Pa 1976) 2005;30:E562-6.
34. Farzanegan GR. Efficacy of pedicle screw fixation in the treatment of spondylolisthesis. Kowsar Med J 2006;11:75-80.